NASA TECHNICAL NOTE

NASA TN D-2044
c.1

NASA TN D-2044

FREE-FLIGHT INVESTIGATION OF THE DEPLOYMENT OF A PARAWING RECOVERY DEVICE FOR A RADIO-CONTROLLED 1/5-SCALE DYNAMIC MODEL SPACECRAFT

by Charles E. Libbey

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1963

TECHNICAL NOTE D-2044

FREE-FLIGHT INVESTIGATION OF THE DEPLOYMENT OF A PARAWING RECOVERY DEVICE FOR A RADIO-CONTROLLED 1/5-SCALE DYNAMIC MODEL SPACECRAFT

By Charles E. Libbey

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FREE-FLIGHT INVESTIGATION OF THE DEPLOYMENT OF A PARAWING RECOVERY DEVICE FOR A RADIO-CONTROLLED 1/5-SCALE DYNAMIC MODEL SPACECRAFT

By Charles E. Libbey

SUMMARY

A free-flight investigation of a radio-controlled model of a manned reentry spacecraft with a telescoping rigid parawing as a recovery system was made to evaluate the deployment process and the stability and control characteristics of the configuration. Flight tests showed that the parawing could be deployed from a packaged condition, but that the deployment process must be a sequence of carefully controlled and timed events, and that some portions of the deployment should not occur at too fast a rate. The most significant single factor learned about the deployment process was that the parawing had to be slowly rotated to a lifting condition. Transition which is too fast from zero lift to maximum lift would result in a tumbling motion. After the parawing was deployed, the configuration was stable and controllable.

INTRODUCTION

A free-flight investigation of a radio-controlled model of a manned reentry vehicle with a parawing for landing has been made as part of an overall study being conducted by the NASA Langley Research Center to determine the feasibility of several applications of the parawing described in reference 1. References 1 to 3 present results of wind-tunnel tests and some uncontrolled flight tests of parawing gliders and illustrate the uses of this configuration as a high-lift device for landing aircraft and as a recovery system for manned space vehicles. Reference 4 presents the results of free-flight deployment tests of a foldable rigid parawing used as a recovery system for a rocket booster. The relatively light weight and small volume of this type of wing also make it attractive for recovery and landing applications of manned reentry spacecraft.

The present investigation was made with a free-flying dynamic model to ascertain a satisfactory method for the deployment of a telescoping rigid parawing from a manned reentry spacecraft and to evaluate qualitatively the stability and flight behavior of the combination for one system of suspension-line geometry and one method of control.

The parawing used for this investigation consisted of a fabric material cut to a 45° sweptback modified-delta planform and attached to three structural members all joined at one end to form the leading edges and the root chord, or keel, of the wing. Use of pivoted joints on the leading edges at the nose of the wing permitted the wing to be retracted into a small spanwise dimension. Use of telescoping structural members for the leading edges and the keel permitted the wing to be retracted into a short chordwise dimension. The spacecraft model used for this investigation was a blunted cone suspended below the parawing by a system of four cables entering the cone near the apex. Radio-control equipment and a motion-picture camera were mounted within the model. The control system utilized for this investigation was to shift the center of gravity of the vehicle fore and aft for pitch control and side to side for roll or lateral control by changing the lengths of the various suspension cables. The deployment of the parawing was accomplished by using a drogue parachute to extract, open, and separate the parawing from the model. The drogue also provided stability to the wing-spacecraft configuration during the deployment process until a flying condition was reached; at that time, the drogue was jettisoned.

FLIGHT-TEST TECHNIQUE, TEST FACILITY, AND EQUIPMENT

The flight-test technique consisted of launching an unpowered radio-controlled model from a helicopter and controlling its flight from the ground. Evaluation of the flight behavior was based on the model pilots' observations and the qualitative information was obtained from motion-picture records.

The flight tests were performed at an open field approximately 1 mile wide and 3 miles long. Two ground stations were used for controlling the model; one for the pilot who operated the pitch controls, and one for the pilot who operated the roll controls. Each ground station was provided with a radio-control unit, communications equipment, and a motorized tracking system equipped with binoculars to assist the pilots and trackers in viewing the flight of the model and with a telephoto motion-picture camera. (See fig. 1.) A helicopter equipped with a special launching rig was used to carry the model to an altitude of approximately 3,000 feet and then release it. The launching rig was mounted on the side of the helicopter near the door (see fig. 2(a)) and was raised and lowered by a hydraulic hoist. When the model was ready to be released, the rig was lowered so that the model was below the helicopter (see fig. 2(b)). Magnetic tape recorders were used to record control signals and all voice communications between the helicopter, coordinator, and model pilots in order to assist in analysis of test results.

MODEL

Parawing

A drawing of the parawing used in the test is presented in figure 3. The flat planform of the wing fabric was a 45° sweepback modified delta; the fabric was attached to a rigid framework which provided 50° of sweepback in flight. This configuration was selected because most of the static wind-tunnel data and dynamic flight-test data available at the time the model was designed had been obtained with this configuration. The size of the parawing was determined by several considerations. First, a full-scale wing loading between 10 and 15 pounds per square foot was desired. Second, it was desired to have only three telescoping sections for each of the structural members from the standpoint of simplicity. And third, the length of the parawing in its packaged condition was not to exceed the length of the side of the spacecraft. Because of these considerations, a full-scale parawing 30 feet long with a wing area of 636 square feet was assumed. Based on a recovery weight of 9,000 pounds, the wing loading was 14.1 pounds per square foot. For the 1/5-scale model, the root chord was 6 feet long as shown in figure 3. The weight of the wing was 6.75 pounds.

The wing was constructed from acrylic-coated 1.2-ounce-per-square-yard nylon ripstop fabric over an aluminum-alloy-tubing framework. The fabric material was essentially nonporous and very flexible as well as being very light. It was cut to the 45° sweepback modified delta planform and had wide casings sewn at the leading edges and root chord to accept the structural members. The trailing edges of the casings were attached to free-floating fabric attachment rings (see detail in fig. 3) on the leading edges and keel. The apex of the fabric was attached to the apex of the aluminum tube framework.

The leading edges and the keel were constructed of three telescoping sections each. Each section had a long straight cylindrical portion with a short flared or tapered portion at the ends (see detail in fig. 3). Thus they were able to form a self-jamming union with the adjoining section when in the fully extended position. This type of construction eliminated the need for any bearings or close tolerance fits in the telescoping sections except for the short flared portions at the ends. Therefore, the telescoping sections could be made with a very loose fit and consequently had low friction between sliding members, thus requiring a minimum force to extend and lock them. When in the fully extended and locked position, the telescoping section had no side or end play.

The two leading edges and the keel were joined to a common flat plate at the forward end, and the two leading edges were hinged on this plate so that they could be folded back along the keel. Two spreader bars were used (one between each leading edge and the keel) to maintain the leading edges at 50° sweepback angle regardless of the various loads imposed on the structure during maneuvering flight. The spreader bars were hinged in the middle and at the points where they joined the leading edges and keel to allow the leading edges to be retracted. A tension device (in this particular case, shock cord) was attached to each spreader bar at its center hinge joint and to the flat plate at the nose of the wing. This tension device was used to force the spreader bars to unfold and thus to force the leading edges to extend to their 50° sweepback, or normal open, position. The spreader bars were self-locking in their unfolded condition and were located as far back from the nose of the parawing as was possible with the following consideration: While the spreader bars were in their folded condition, they were not to extend past the ends of the leading edges and the keel while the leading edges and the keel were in their telescoped condition (in order not to increase the overall length of the parawing package). This arrangement required a minimum tension force (consistent with a short package length) to unfold the spreader bars.

Spacecraft

A drawing of the spacecraft model is presented in figure 4. It is a symmetrical blunted cone with a maximum diameter of 31 inches. The weight of the spacecraft model, including the weight of all the equipment mounted in it was 78.25 pounds. The equipment was installed in the model in the most convenient manner and in such a location that the center of gravity of the spacecraft was located on the axis of symmetry and 5.85 inches above the plane of maximum diameter, as shown in figure 4, but no attempt was made to ballast the model for any particular moments of inertia.

Suspension System

The spacecraft was suspended below the parawing by a system of four nylon cables of 3/16-inch diameter. Two of the cables were attached to the keel of the parawing; the location of the attachments on the keel was influenced by the following considerations: First, the attachment points had to be far enough apart to prevent either of the cables from becoming slack during gliding or maneuvering flight; second, they had to be close enough together so as not to require large changes in cable lengths to provide adequate pitch control; and third, they had to be located so that they did not require excessive forces for pitch control. The length of the forward and rearward suspension lines, with the controls neutral was 68 and 60.5 inches, respectively. The other two cables were attached one to each leading edge and were used for roll control. They were so located that they were unaffected when pitch control was applied. These lines were $67\frac{5}{8}$ inches long.

Controls

The flight control system, together with certain elements of the deployment control system and an emergency recovery system were housed in the spacecraft. The flight control system consisted of electric motor actuators which provided flicker, or bang-bang, control in which the pitch and roll controls were moved rapidly to predetermined positions in either direction from the neutral position in response to control signals and then back to neutral with the cessation of the signal. An electric-motor-driven winch was used as part of the deployment system to control the rate at which the parawing separated from the spacecraft. This winch extended a line at an approximately constant rate for as long as its radio signal was being given and remained fixed when the signal was stopped. A 12-foot emergency parachute was installed in the model to facilitate a safe landing and minimize damage if the parawing did not deploy properly. A pyrotechnic device was used to actuate the parachute and was controlled by radio from the ground.

Parawing Packaging

The packaged parawing was arbitrarily attached to the outside of the spacecraft for reasons of mechanical simplicity. On the premise that the full-scale parawing would be contained within the vehicle, the suspension lines were made long enough so that they would permit the extraction of the entire length of the parawing through a hatch at the apex of the spacecraft. Such a suspension system would allow the sides of the spacecraft to be a continuous unit with no doors or blow-away panels along its length.

The parawing was contained in a deployment bag to facilitate packing and handling problems and also to protect the wing fabric and suspension cables from the airstream during the early stages of the deployment process. The bag was just long enough to completely encase the parawing with the structural members fully collapsed.

Drogue Parachute

A drogue parachute was used to control the deployment sequence since it was easy to install, had excellent reliability, required little volume, and produced relatively large forces for long periods of time. The drogue was made to perform many functions. First, it pulled the deployment bag off the parawing and extended the leading edges and the keel to their full length from their telescoped condition; second, it pulled a pin which activated the tension devices attached to the spreader bars forcing them to unfold and lock with the parawing at its 50° sweepback condition; and third, it separated the wing from the spacecraft and caused it to rotate up into its flying attitude. The drogue also added stability to the configuration during the deployment process.

TESTS

Flight tests of the model were made by launching it from a helicopter at an airspeed of near zero knots at an altitude of approximately 3,000 feet. The deployment tests of the wing were started at approximately 2,500 feet and were usually completed by approximately 1,500 feet. At the average deployment altitude of 2,000 feet (air density of 0.002242 slug/cu ft) and the assumed 1/5 scale, the model dynamically simulated a full-scale reentry vehicle with a gross weight of 9,000 pounds at an approximate altitude of 7,500 feet. For these test conditions, the total flying weight of the spacecraft plus the parawing was 85 pounds. The tests were made with the effective center of gravity of the parawing-spacecraft combination located 65 percent of the keel length back from the apex of the wing and 81 percent of the keel length below the keel. Reference 5 indicates that this configuration has static longitudinal stability with this center-of-gravity location.

The tests consisted of a series of flights to determine a deployment sequence for satisfactory transition between a spacecraft in its reentry configuration with a rigid-parawing recovery system stowed onboard and the trimmed gliding-flight configuration with the spacecraft suspended below the parawing. In order to isolate the deployment problems and be able to correct them one at a time, a systematic series of tests was conducted beginning with free-flight tests of the parawing-spacecraft configuration being released from the helicopter in the trimmed gliding condition, and progressing in a reverse sequence one phase at a time until finally the spacecraft was released from the helicopter with the parawing completely collapsed, stowed on board, and deployed during free vertical descent. No complete deployment test starting with the parawing packed in the deployment bag on the side of the spacecraft and ending with the spacecraft and parawing in gliding flight was conducted during a single flight.

A qualitative evaluation of the stability of the configuration with its particular suspension-line geometry and the effectiveness of shifting the center of gravity as a means of control was also made as the model glided to the ground following some of the deployment tests.

Evaluation of the flight characteristics was based on qualitative observations of the control by the observers and on the quantitative measurements obtained from motion-picture records. The motion pictures were taken from the ground and from the helicopter.

RESULTS AND DISCUSSION

A motion-picture film supplement covering flight tests of the model has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this paper on the page with the abstract cards.

Deployment Sequence

Not all deployment attempts were successful, but much useful data were obtained from the unsuccessful attempts which pointed the way to the final satisfactory deployment sequence.

The complete successful deployment sequence as finally derived is shown step by step in the static displays in figure 5. Figure 5(a) shows the model with the parawing packaged in a deployment bag on the side of the spacecraft. A drogue parachute is attached to the spacecraft with a three-point bridle, and a separate line is attached to the end of the deployment bag. The bottom of the deployment bag is secured to the spacecraft with break cords. Figure 5(b) shows the model with the drogue released from the spacecraft and the deployment bag pulled off the parawing. The drogue line is now attached to the ends of the telescoping tubes. The parawing is still in its packaged condition. Figure 5(c) represents the model just after the drogue has pulled the telescoping tubes to their fully extended positions and just prior to unfolding the parawing. Figure 5(d) shows the parawing unfolded but with the nose still attached to the spacecraft. The drogue parachute is now attached to the parawing by a three-point bridle, one point at the apex and one point on each of the leading edges at the location of the roll-control lines. Figure 5(e) shows the position of the parawing just after the nose is released from the spacecraft. The drogue parachute is providing a force to pull the parawing away from the spacecraft and at the same time is causing the parawing to pitchup so as to start producing lift. Figure 5(f) represents the parawing position approximately halfway through the transition phase. Note that the drogue chute is still attached to the parawing. Figure 5(g) illustrates the parawing and spacecraft in the gliding condition. The drogue parachute is released soon after this condition has been reached. Of course, in figures 5(e) to 5(g) the sail is not filled, since the photographs were taken with the model hanging up in still air.

As pointed out previously, no complete deployment was carried out in one flight. Each phase of the deployment was flight tested in sequence with sufficient overlap of the deployment phases from one flight to the next to insure that the operation of one phase does not interfere with the successful operation of the succeeding phases. The deployment steps as illustrated in figures 5(a) to 5(d) were conducted during one flight. Then the steps illustrated in figures 5(c) to 5(g) were conducted in another flight except that the drogue parachute was not released. And, finally, the steps as illustrated in figures 5(d) to 5(g) were conducted in one flight and included the release of the drogue parachute. It should be remembered, however, that the tests were actually conducted in a reverse sequence.

Glide Tests

The model was tested in a gliding condition before any deployment attempts were made in order to obtain a trim condition near the maximum lift-drag ratio and also to determine the control travels necessary for maneuvering.

As pointed out previously, a center-of-gravity location of 65 percent of the keel length back from the apex and 81 percent of the keel length below the keel for the spacecraft-parawing combination was arrived at as being the location which would be used during the deployment tests. With this center-of-gravity location, the model appeared to have a smooth and relatively flat glide path. The model was longitudinally and laterally stable and did not appear to have any rolling, pitching, or yawing oscillations, and no flutter was observed in the wing fabric. Pitch control was achieved by moving the center of gravity ±6 percent of the keel length from the neutral position at a rate of approximately 10 percent per second. Although this rate produced large pitching velocities, it was not fast enough to make control of the model difficult. The 6-percent travel to either side of neutral was sufficient to maneuver the model from a steep dive to beyond stall. Roll control was achieved by rolling the wing $\pm 3^{\circ}$ about the axis of the keel which corresponded to a lateral shift in the center of gravity of ±5 percent of keel length. A control rate of approximately 10 percent per second produced satisfactory lateral control.

Separation of Parawing From Spacecraft and Rotation to Flying Attitude

The first phase of the deployment sequence to be investigated after the gliding flights was the separation of the parawing from the spacecraft and rotation of the wing up to its flying attitude. For this phase of the tests, the parawing was attached to the spacecraft with the structural members fully extended and the spreader bars opened and locked, holding the leading edges at the 50° sweepback condition. The nose of the parawing was attached to the spacecraft by a sliding bolt which could be released by an electric motor actuator responding to a radio signal from the ground. Even though the parawing separated from the spacecraft, it would not pitch up into a flying attitude so as to start producing lift. The spacecraft and parawing fell in this condition until the flight had to be terminated with an emergency recovery parachute.

To solve this problem, a line from a drogue parachute was attached at the nose of the parawing to produce a pitching moment. The effectiveness of this arrangement was investigated in the Langley 20-foot free-spinning tunnel (ref. 6). The tests showed that this arrangement in itself was not a complete solution since on some occasions, the parawing would not pitch up but rather would yaw to one side or the other and thus fail to develop lift. Therefore, two additional lines from the drogue parachute were added to the parawing; one line was attached to each of the leading edges so that the tension in the line from the drogue parachute prevented the parawing from yawing but left it free to pitch up. (See figs. 5(e) and 5(f).) The three lines from the drogue were run through eyelets on the parawing to a common point on the keel to facilitate release of the drogue at the end of the deployment sequence. For purposes of mechanical simplicity the drogue was automatically jettisoned as soon as the parawing was in its normal flying condition.

Outdoor free-flight tests revealed that if the parawing were allowed to pitch up quickly, and if it were unrestrained except by the suspension lines, extremely high loads were imposed on the suspension system. Also the parawing made an almost instantaneous transition from 0° angle of attack to 90° angle of attack. At 90° angle of attack, there was a large nose-down pitching moment since the trim angle of attack for the parawing-spacecraft combination was approximately 25°. The parawing would pitch down so rapdily that it would not stop at its trim angle of attack but would continue pitching so as to enter a tumbling condition. When the parawing-spacecraft combination became inverted, the spacecraft fell onto the wing. Because of the geometry of the spacecraft, it would usually roll off the wing; however, the model did not achieve the desired trim gliding flight from this condition. Sometimes the lines became entangled and sometimes the wing stabilized in a vertical dive at a condition of zero angle of attack and zero lift. Keeping the drogue attached to the parawing for a longer time alleviated the tumbling problem but did not reduce the high loads imposed on the system by a nearly instantaneous transition from low drag at 0° angle of attack to high drag at an angle of attack of 90°. Therefore, a snubber line was attached between the nose of the parawing and the spacecraft. This line limited to approximately 20° the initial pitch travel of the wing when it was separated from the spacecraft. From this position the snubber line was extended by a motor-operated winch until it finally became slack and all the load was being carried by the suspension lines. At this time the drogue parachute was automatically jettisoned. The extension of the snubber line on the model required approximately 6 seconds. No attempt was made to determine the fastest rate at which the snubber could be extended without causing a tumbling motion, but it is believed that rates faster than those used are possible. Extending the snubber line slowly allowed the parawing-spacecraft configuration to make a smooth transition from a vertical descent with zero lift to a gliding descent with the configuration trimmed at approximately its best lift-drag ratio.

Opening the Wing

The next step backward in the deployment process was to retract the leading edges until they were parallel to the keel. At this stage, a deployment bag was used to protect the parawing fabric and suspension lines from the airstream before the deployment process was begun. It also facilitated the packing and handling of the wing. The forward end of the deployment bag was attached to the nose of the parawing by a lightweight cord to prevent the bag from blowing off prematurely. This cord was broken easily and the bag was quickly pulled off the parawing when the load from the drogue parachute was applied to the back end of the deployment bag. This was accomplished when the bridle lines between the drogue and the spacecraft were released, automatically transferring the load of the drogue to the bag. After the bag was pulled clear of the parawing, the load from the drogue was transferred to the three-line bridle used to pitch the wing up to its gliding attitude. Several tests were conducted in the Langley 20-foot free-spinning tunnel to investigate the operation of the system. From these spin-tunnel tests, the amount of tension required to spread the leading edges to their 50° sweepback condition was determined, and a system of packing the wing fabric and the suspension lines was devised which prevented entanglements and did not hinder deployment. Steel aircraft cables were tested as suspension lines, but proved to be too stiff for efficient packing. Therefore, nylon cables were used on the final configuration. Once the technique had been worked out in the tunnel, outdoor free-flight tests were conducted to confirm the tunnel results.

The last phase to be checked in the deployment sequence was that of unpackaging the wing and extending the telescoped members. This phase was also checked in the Langley 20-foot free-spinning tunnel prior to the outdoor free-flight test. For this phase of the tests, the drogue parachute had to extend and lock the telescoping members. This was accomplished by securing the line from the drogue parachute first to the end of the keel, then to the end of one of the leading edges, and finally to the end of the other leading edge. The drogue line had enough slack between the ends of the telescoping members so that the keel could be fully extended and locked without pulling on the first leading edge, and then the first leading edge could be extended without pulling on the second leading edge. After the keel was extended, a reefing line cutter was used to separate the drogue line from the end of the keel and thus allow the load to be transferred to the end of one of the leading edges causing it to be extended next. In a similar manner, the final leading edge was extended and the drogue line was released from it so as to transfer the load of drogue to the bridle on the wing. This sequence was used to obtain the full force of the drogue parachute on each of the telescoping members. Tests showed that if all the telescoping members were extended at one time, all the flare joints would not jam consistently. There would be a random failure with no particular joint being more susceptible to failure than any other. As an added safety feature, small spring-loaded pins were made to drop into position to prevent the telescoping tubes from retracting once they were extended. Sometimes when all the tubes were extended simultaneously, one of the sections would fail to travel far enough to allow the spring-loading pin to drop into the lock position. Extraction of the telescoping tubes one at a time eliminated this situation.

CONCLUDING REMARKS

In general, the flight tests showed that the radio-controlled model of the parawing-spacecraft configuration was stable and could be controlled by shifting the center of gravity. The deployment system which was developed is a satisfactory method for use with a telescoping rigid parawing. The deployment process of the parawing, however, must be a sequence of carefully controlled and timed events, and some portions of the deployment should not occur too quickly. The most significant single factor learned about the deployment process was that the parawing had to be slowly rotated to a lifting condition since too fast a transition from zero lift to maximum lift would result in a tumbling motion.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 3, 1963.

REFERENCES

1. Rogallo, Francis M., Lowery, John G., Croom, Delwin R., and Taylor, Robert T.: Preliminary Investigation of a Paraglider. NASA TN D-443, 1960.

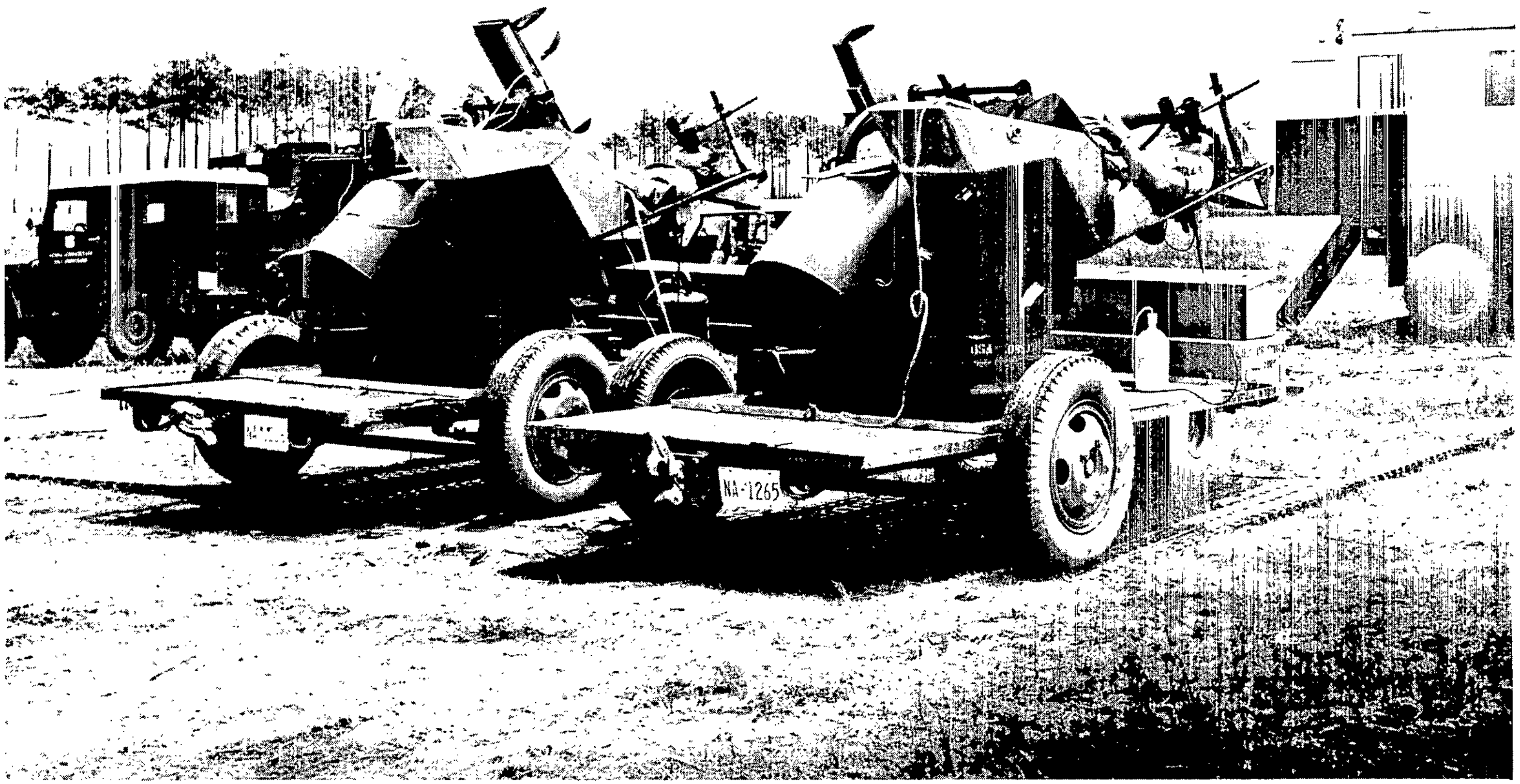
2. Rogallo, F. M., and Lowery, J. G.: Flexible Reentry Gliders. Preprint No. 175C, Soc. of Automotive Eng., Apr. 1960.

3. Naeseth, Roger L.: An Exploratory Study of a Parawing as a High-Lift Device for Aircraft. NASA TN D-629, 1960.

4. Burk, Sanger M., Jr.: Free-Flight Investigation of the Deployment, Dynamic Stability, and Control Characteristics of a 1/12-Scale Dynamic Radio-Controlled Model of a Large Booster and Parawing. NASA TN D-1932, 1963.

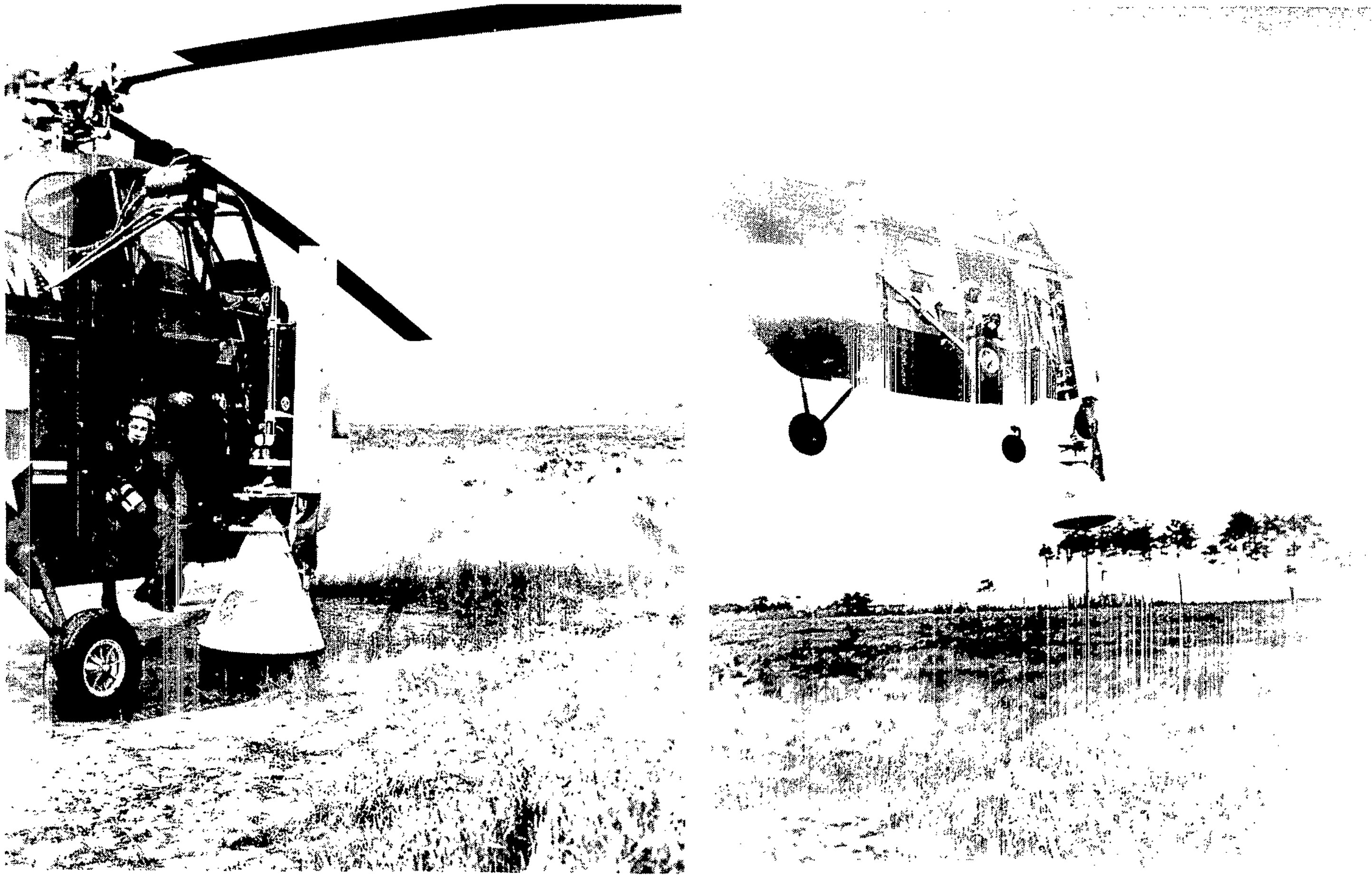
5. Hewes, Donald E.: Free-Flight Investigation of Radio-Controlled Models With Parawings. NASA TN D-927, 1961.

6. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. NACA Rep. 557, 1936.



L-61-4144

Figure 1.- Photograph of ground stations showing the roll-yaw pilot and pitch pilot in position.



(a) Model raised. L-61-273

(b) Model lowered. L-61-274

Figure 2.- Photograph of model on launch rig in raised and lowered positions.

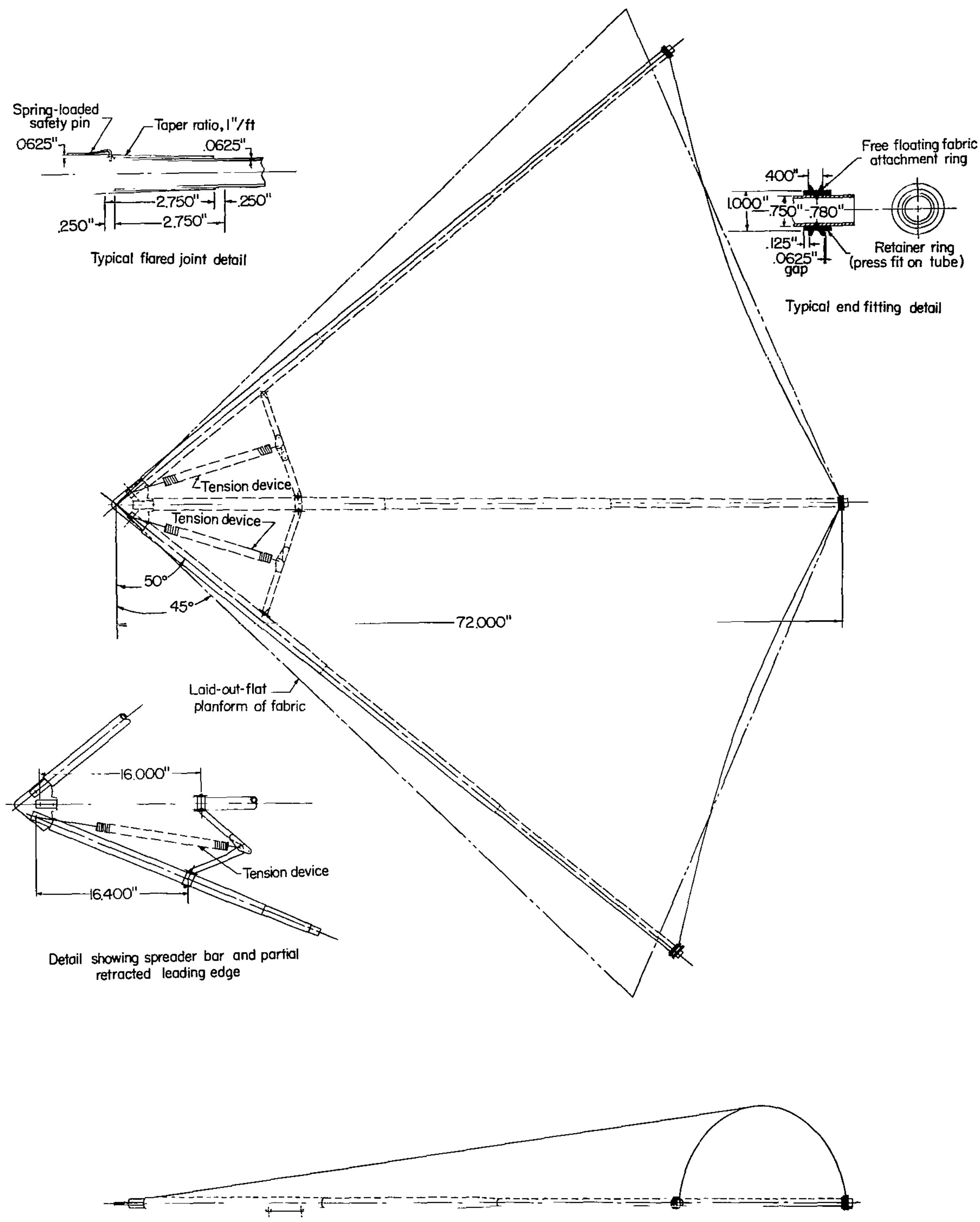


Figure 3.- Two-view drawing of telescoping parawing.

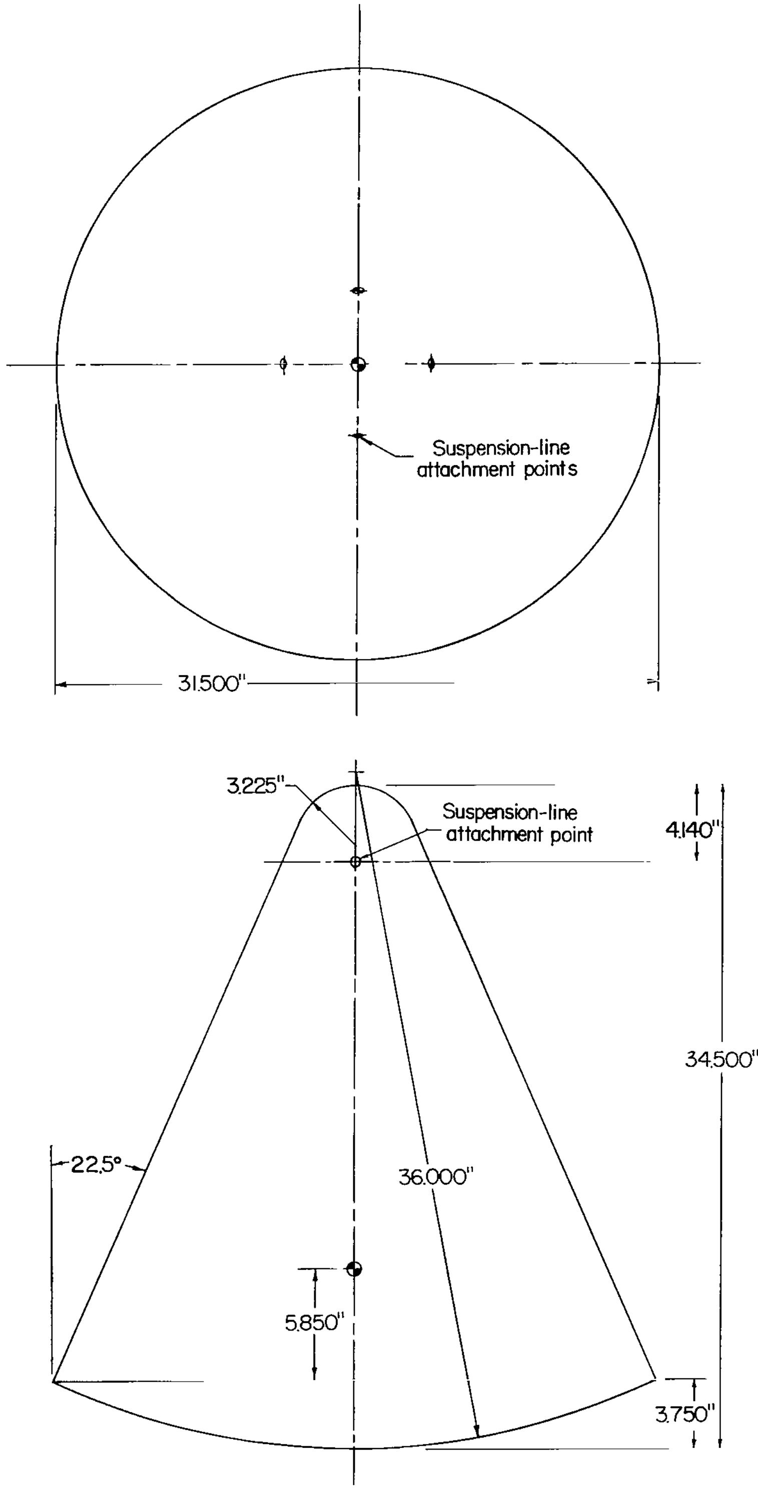
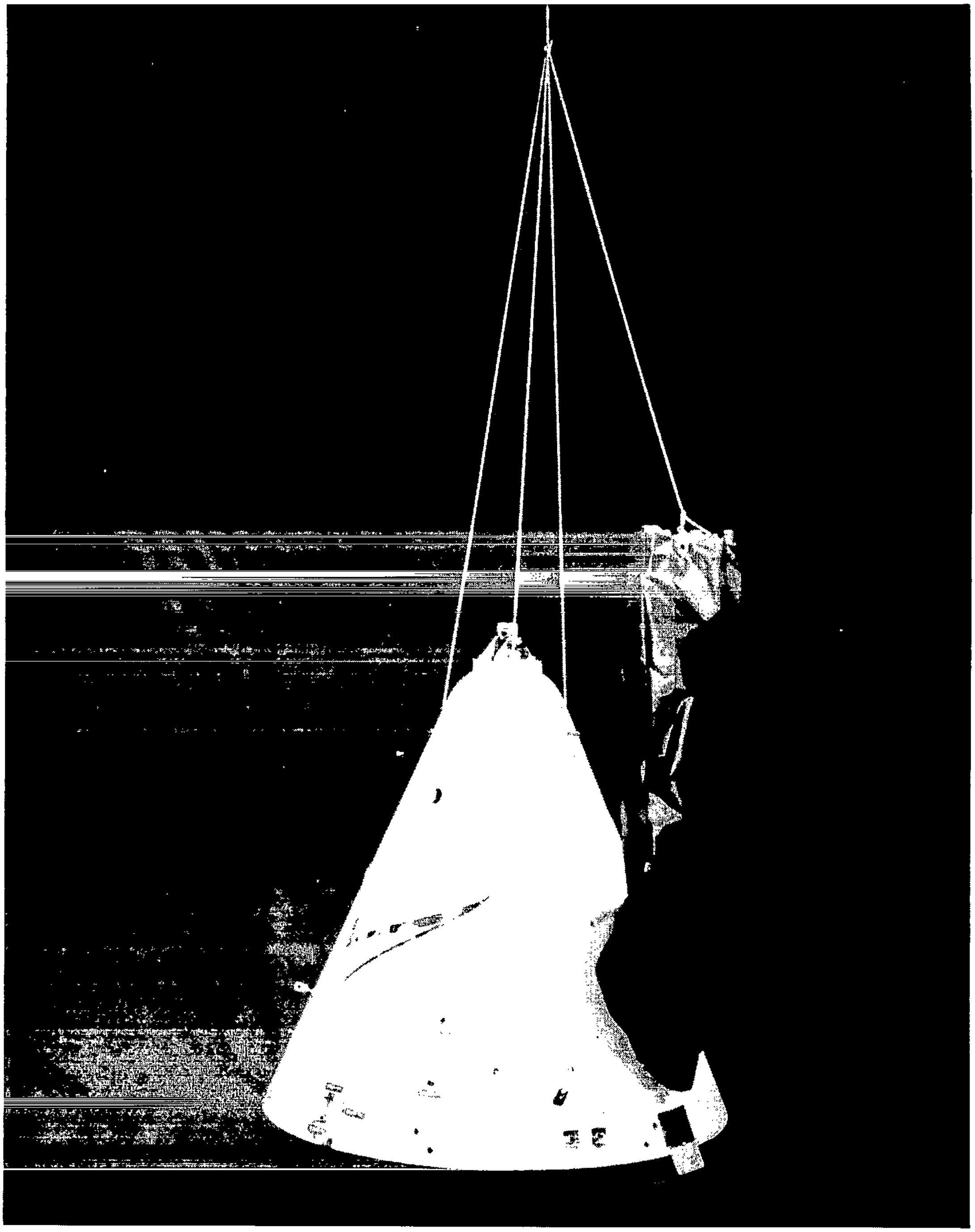
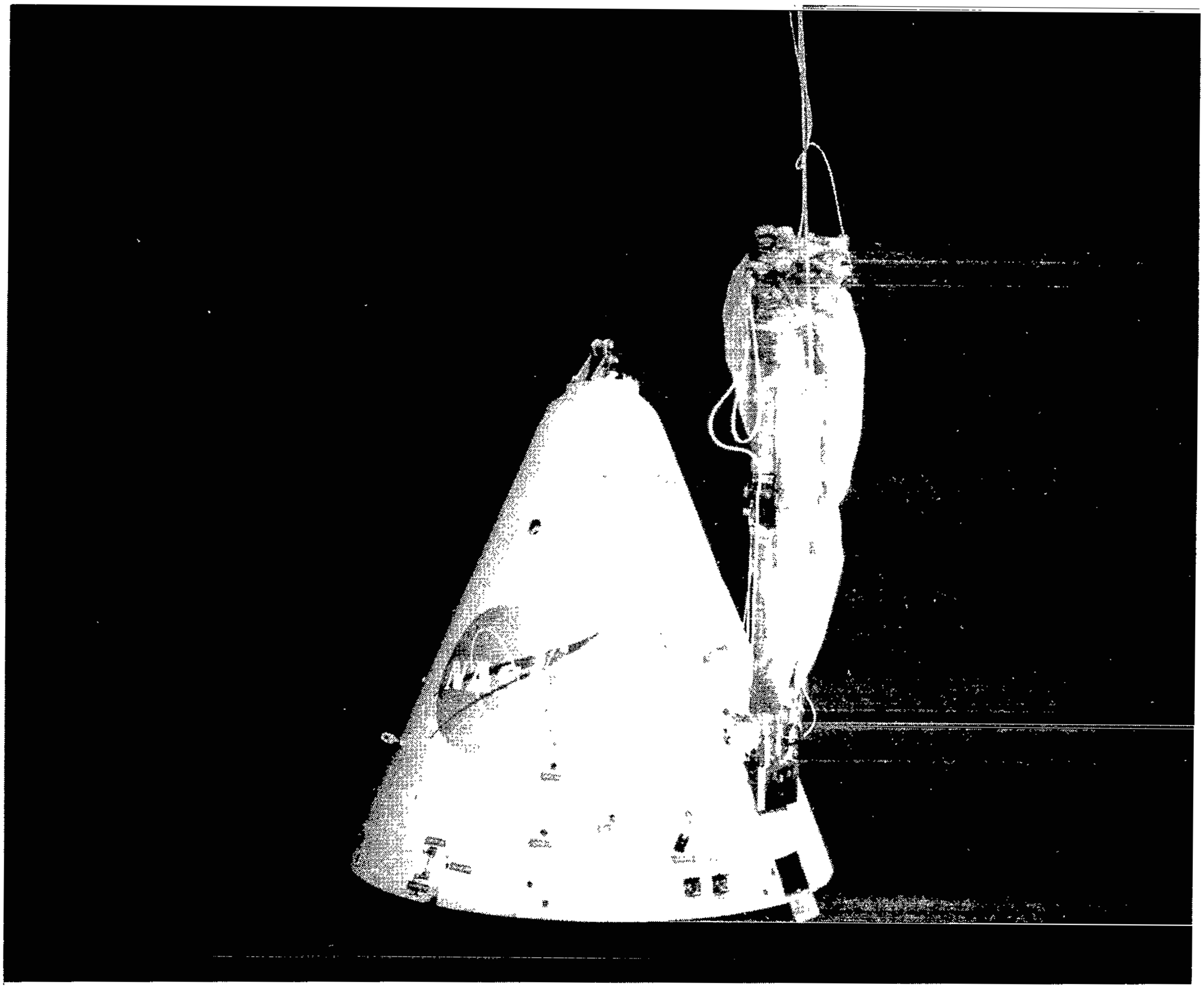


Figure 4.- Two-view drawing of model spacecraft.



(a) Spacecraft with parawing stowed onboard. L-63-4752

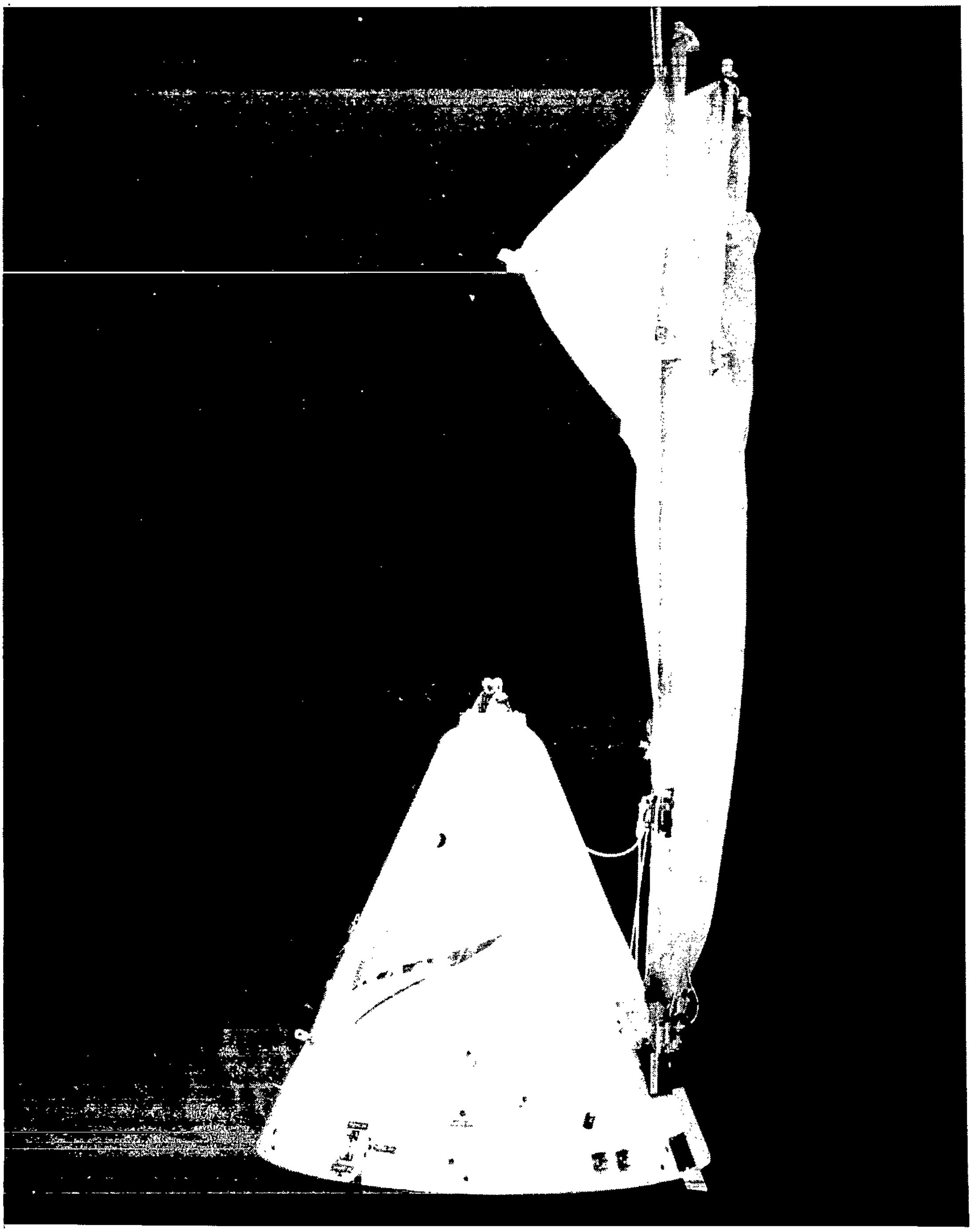
Figure 5.- Deployment sequence.



L-63-4753

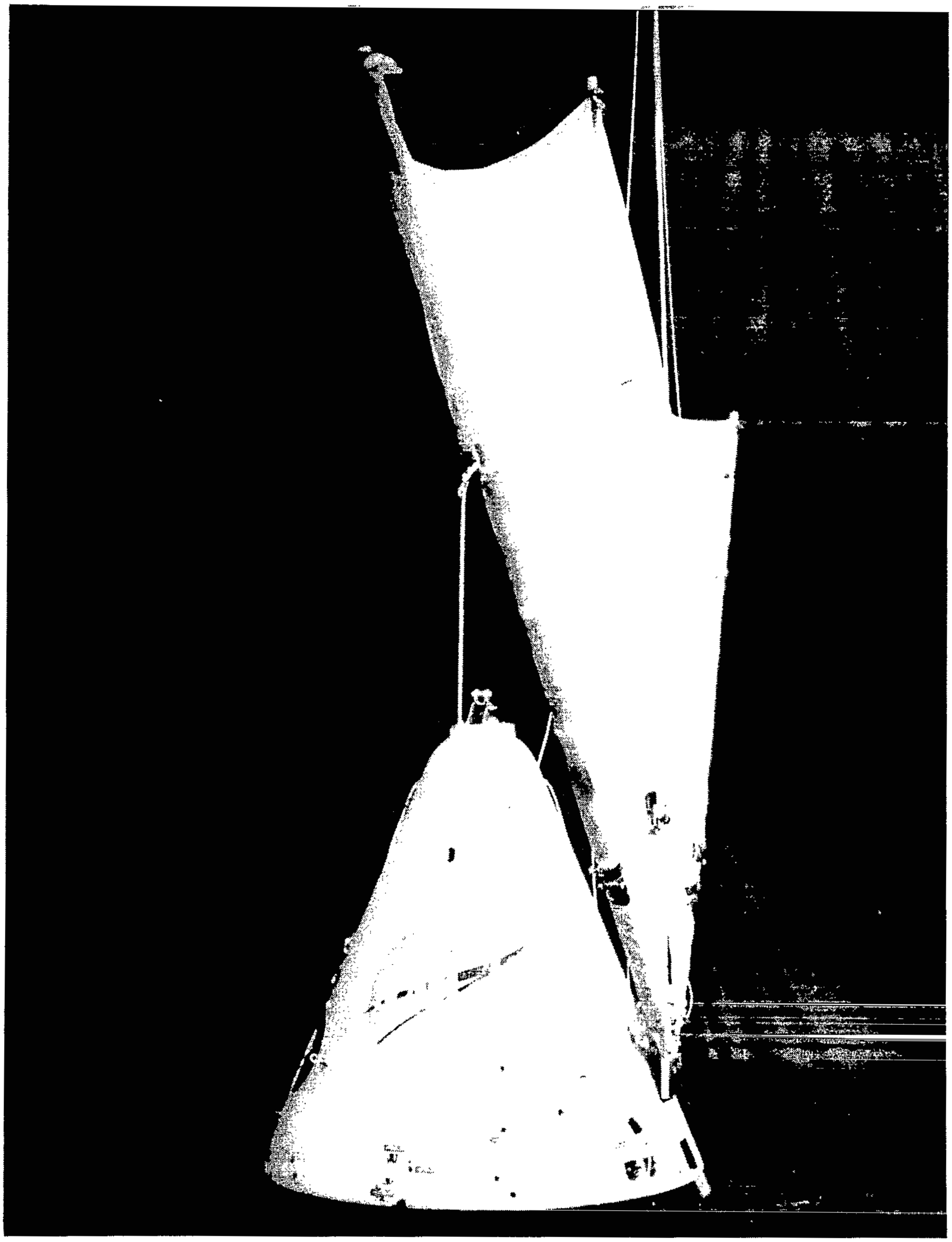
(b) Drogue parachute released from spacecraft and deployment bag pulled off parawing.

Figure 5.- Continued.



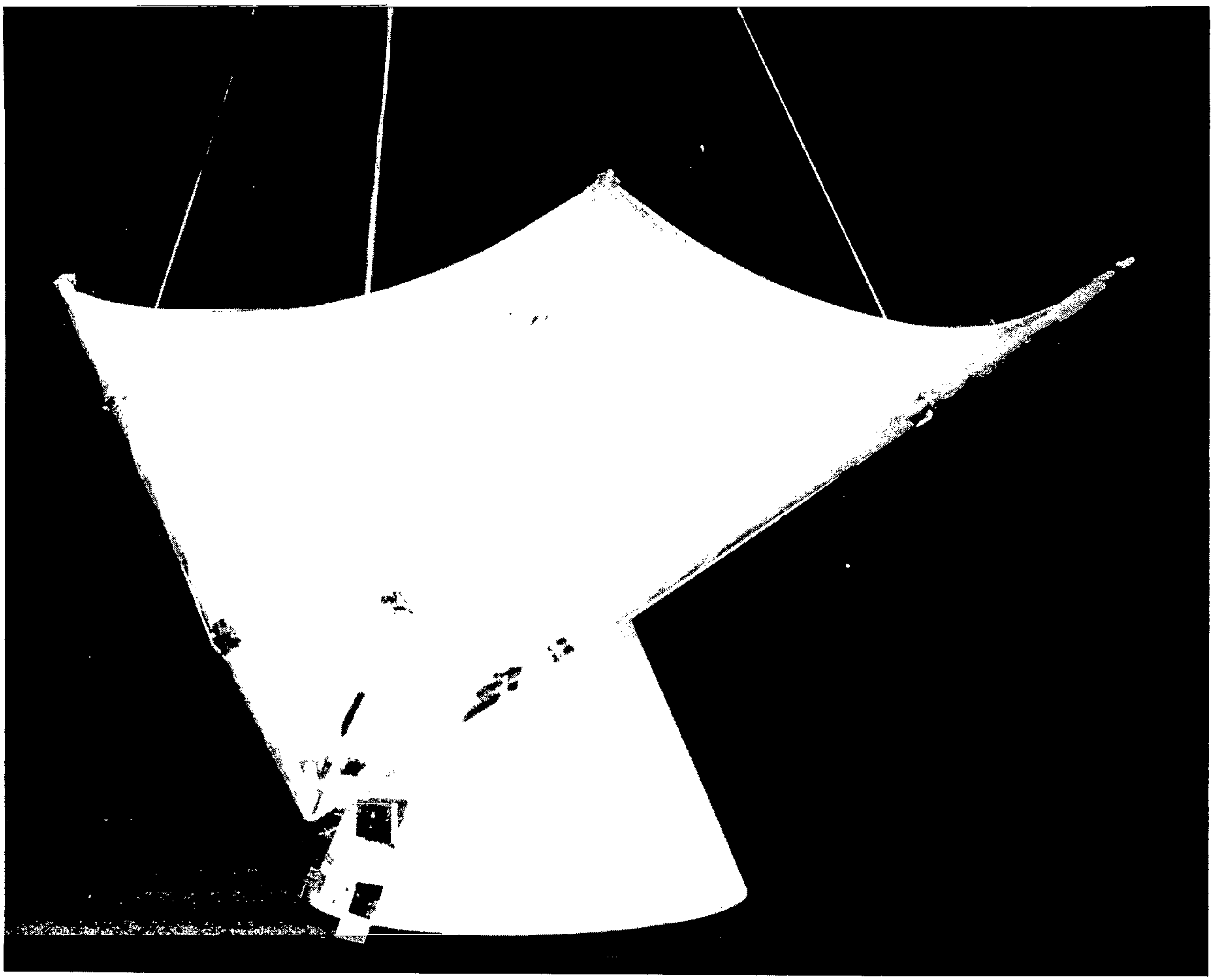
(c) Telescoping tubes extended by means of the drogue parachute. L-63-4754

Figure 5.- Continued.



(d) Leading edges spread to 50° sweepback position. L-63-4755

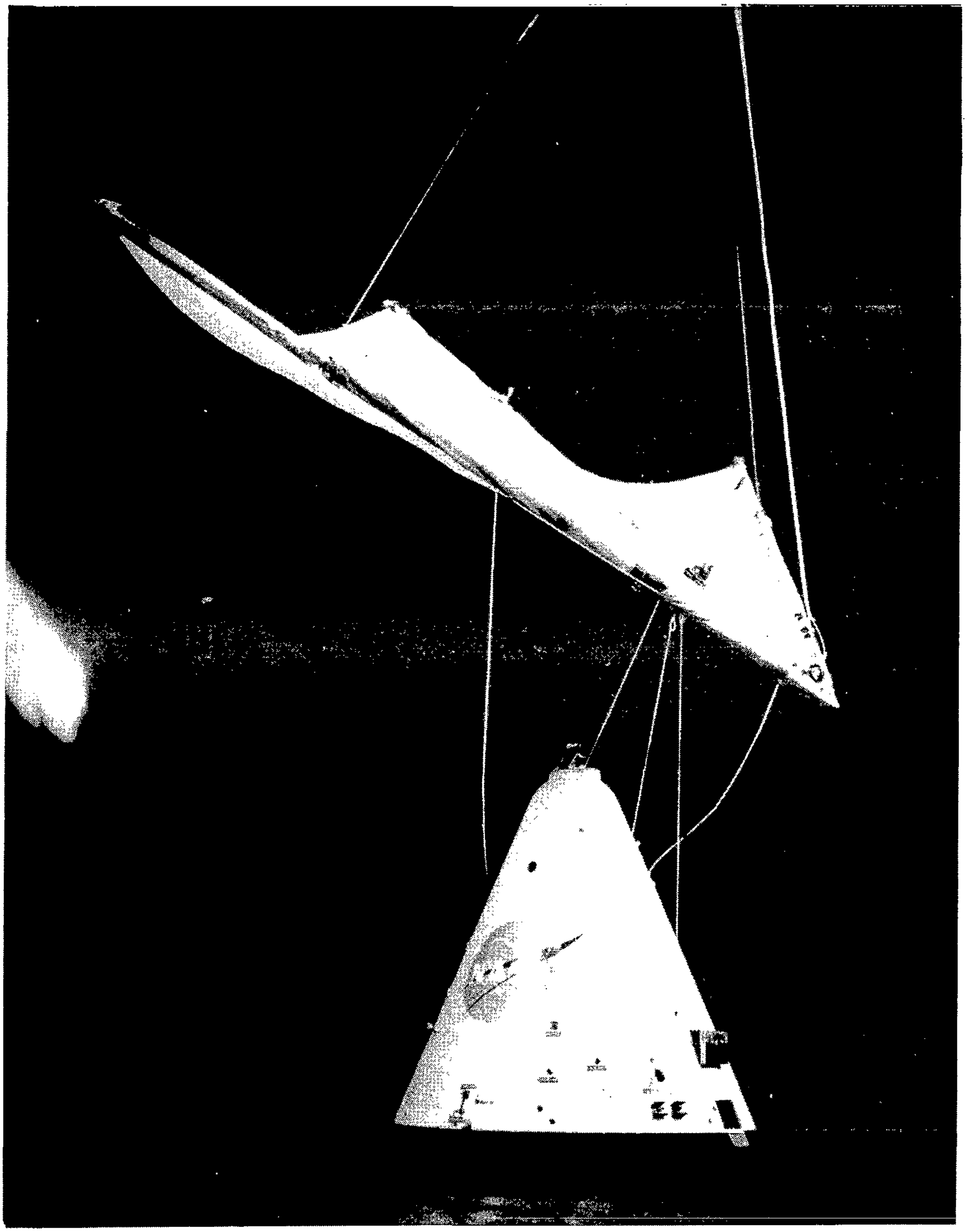
Figure 5.- Continued.



L-63-4756

(e) Apex of parawing released from spacecraft, drogue starting to rotate parawing to lifting condition.

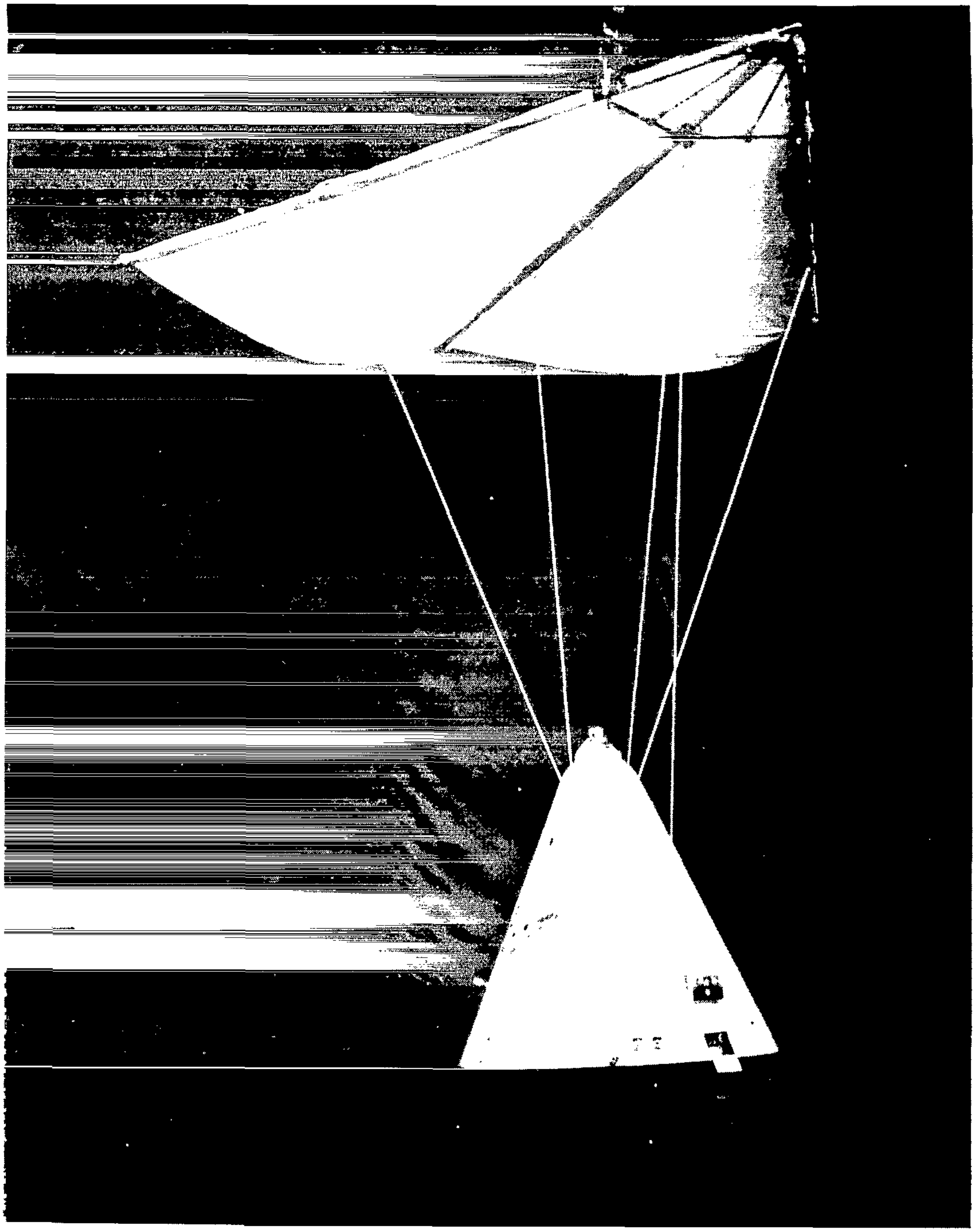
Figure 5.- Continued.



L-63-4757

(f) Parawing approximately halfway through the transition from zero lift to gliding flight condition.

Figure 5.- Continued.



(g) Parawing-spacecraft configuration in final gliding flight condition. L-63-4758

Figure 5.- Concluded.